Multi-instrument measurements of stable cycles at Erebus lava lake, Antarctica

N. Peters, T. Ilanko, C. Oppenheimer, N. Kingsbury
University of Cambridge, Cambridge, UK

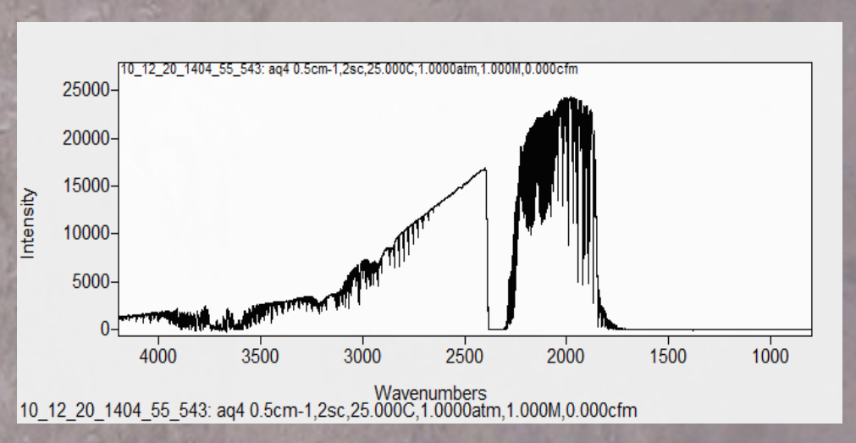
Introduction

Situated on Ross Island, Antarctica, the 3794 m high crater of Mt. Erebus has maintained an active phonolite lava lake for decades. As the exposed top of the magmatic plumbing system, the behaviour of the lake is intrinsically linked to the deeper processes of the volcano. A multi-instrument campaign to better understand the dynamics of the lake has been under way since 2004. Several new techniques have been developed to study different aspects of the lake's behaviour. While the data analysis is still at an early stage, initial results show that the lake exhibits cyclic behaviour in many of its properties. Furthermore the period of the cycles has remained surprisingly constant since data collection began.

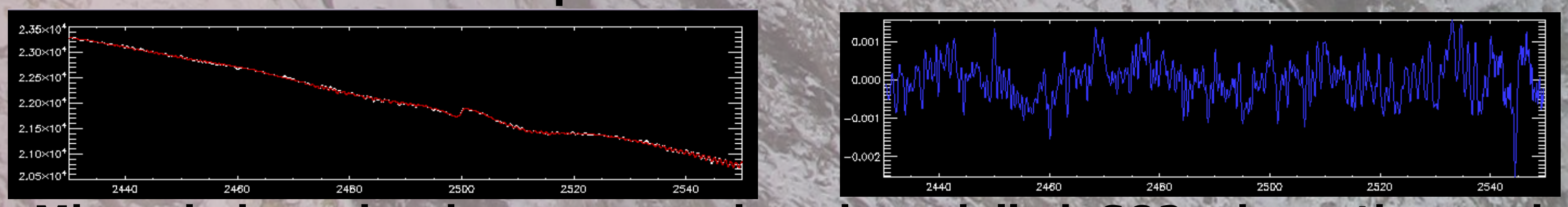
Gas Composition

Fourier Transform Infrared (FTIR) Spectroscopy involves the measurement of infrared radiation passing through gas, where absorption at wavelengths characteristic of different chemical bonds allows the molecular gases present to be identified and quantified. Erebus has a natural advantage in that the lava lake provides an infrared source for open-path measurements. Data are stored as interferograms, which record incoming radiation as the combined intensity of all wavelengths, rather than scanning through selected wavelengths, enabling high speed data collection.

A MIDAC FTIR spectrometer with an Indium-Antimonide detector is used for most of the plume gas measurements at Erebus lava lake. This detector is sensitive to radiation over a wavenumber range of 1800-6000 cm-1. The spectrometer and telescope are mounted on a tripod at the crater rim, about 340 m from the surface of the lava lake. The detector is cooled by liquid nitrogen, which must be refilled at intervals of about 12 hours. Interferograms are recorded to a laptop connected directly to the spectrometer. Co-adding of spectra to improve the signal-to-noise ratio is possible, although this reduces the data collection rate. Data are later converted to single beam spectra using the MIDAC software AutoQuant Pro.



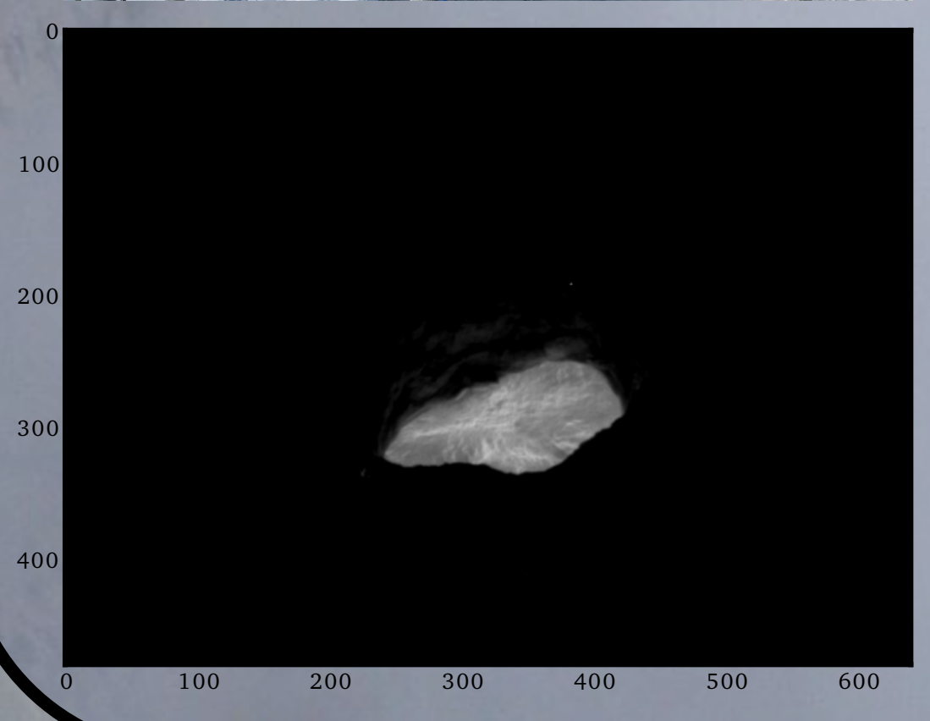
Gas abundances are retrieved from the single beam spectra using an IDL code, based on the Reference Forward Model and developed by Mike Burton. The code references synthesised absorption data from the HITRAN molecular database. Given a set of inputs, it generates a least squares best fit for each single beam spectrum. Inputs include: volcanic and atmospheric gas species present, pressure and temperature of volcanic gas and atmosphere, path length, and field of view of the spectrometer. Fitting is carried out over a microwindow, which can be selected to minimise interference from other gases. In addition to retrieved column amounts, the model calculates goodness of fit between the measured and fitted spectra.



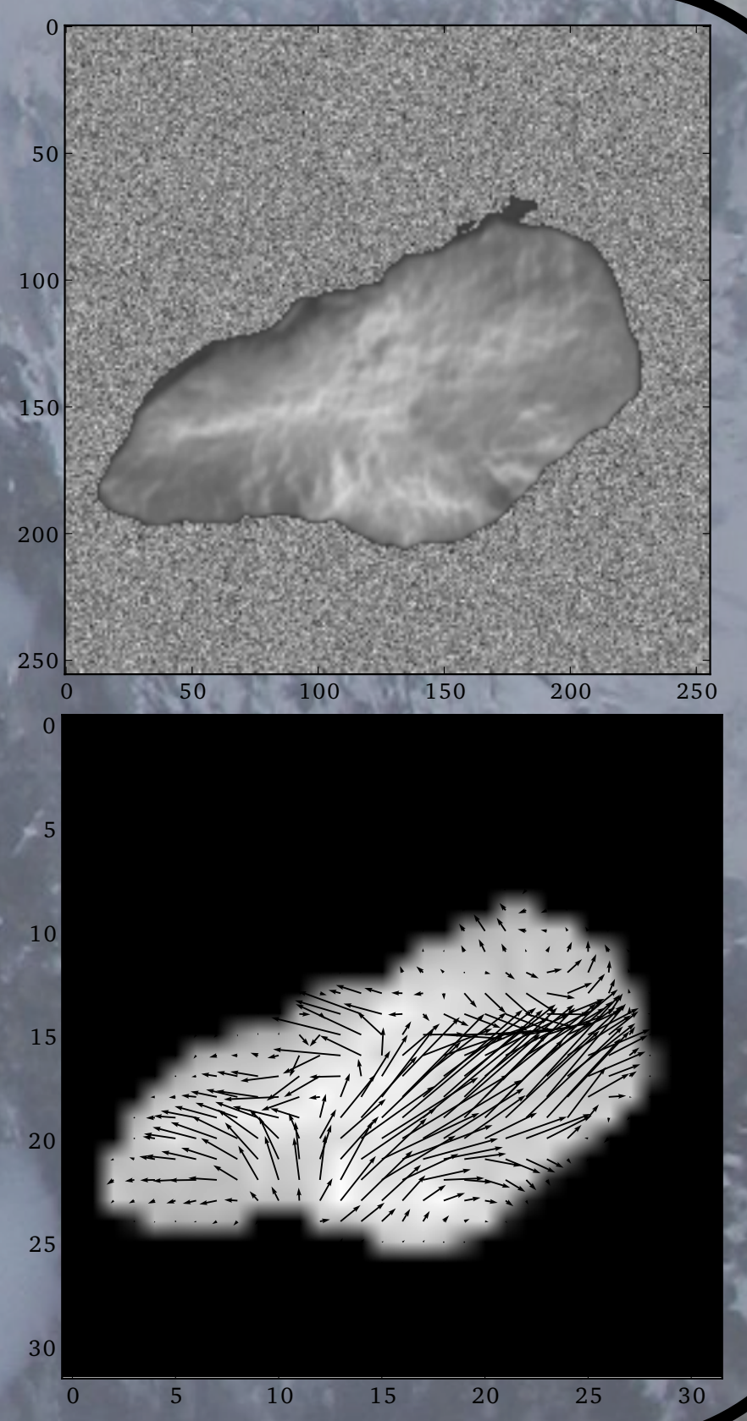
Microwindow showing measured and modelled SO2 absorption and residual after modelling

Surface Velocity

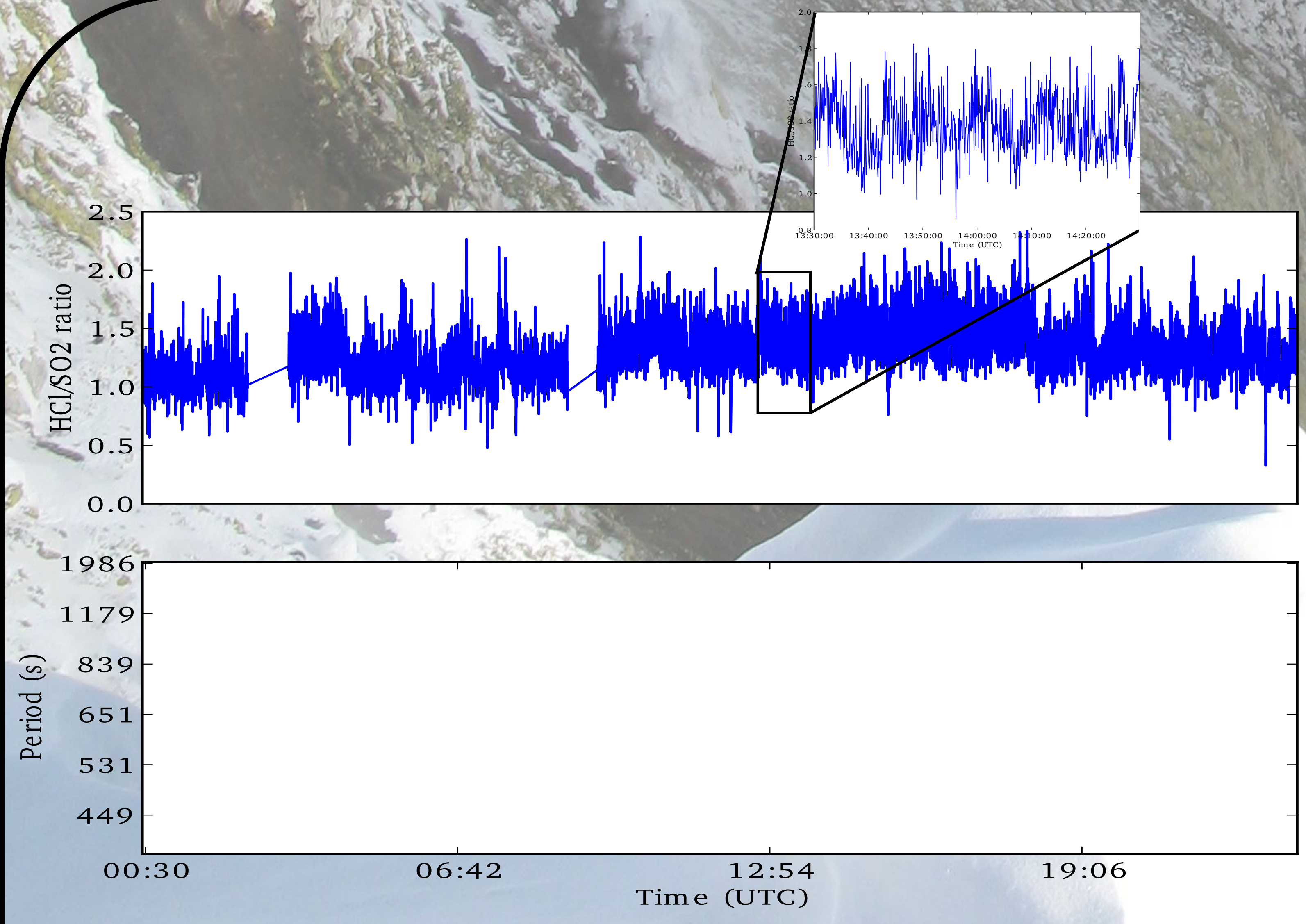
Due to the constantly changing atmospheric conditions within the crater, thermal imagery is unable to accurately resolve the absolute surface temperature of the lake. However, even when the lake is entirely obscured by the volcanic plume (to the naked eye), thermal cameras are still able to produce clear images of the lake. The high degree of texture in the images allows feature tracking to be used to determine the two-dimensional velocity field of the lake surface. It is found that the surface velocity exhibits periodic behaviour on a time-scale of approximately 14 minutes, with regular intervals of high and low velocity.



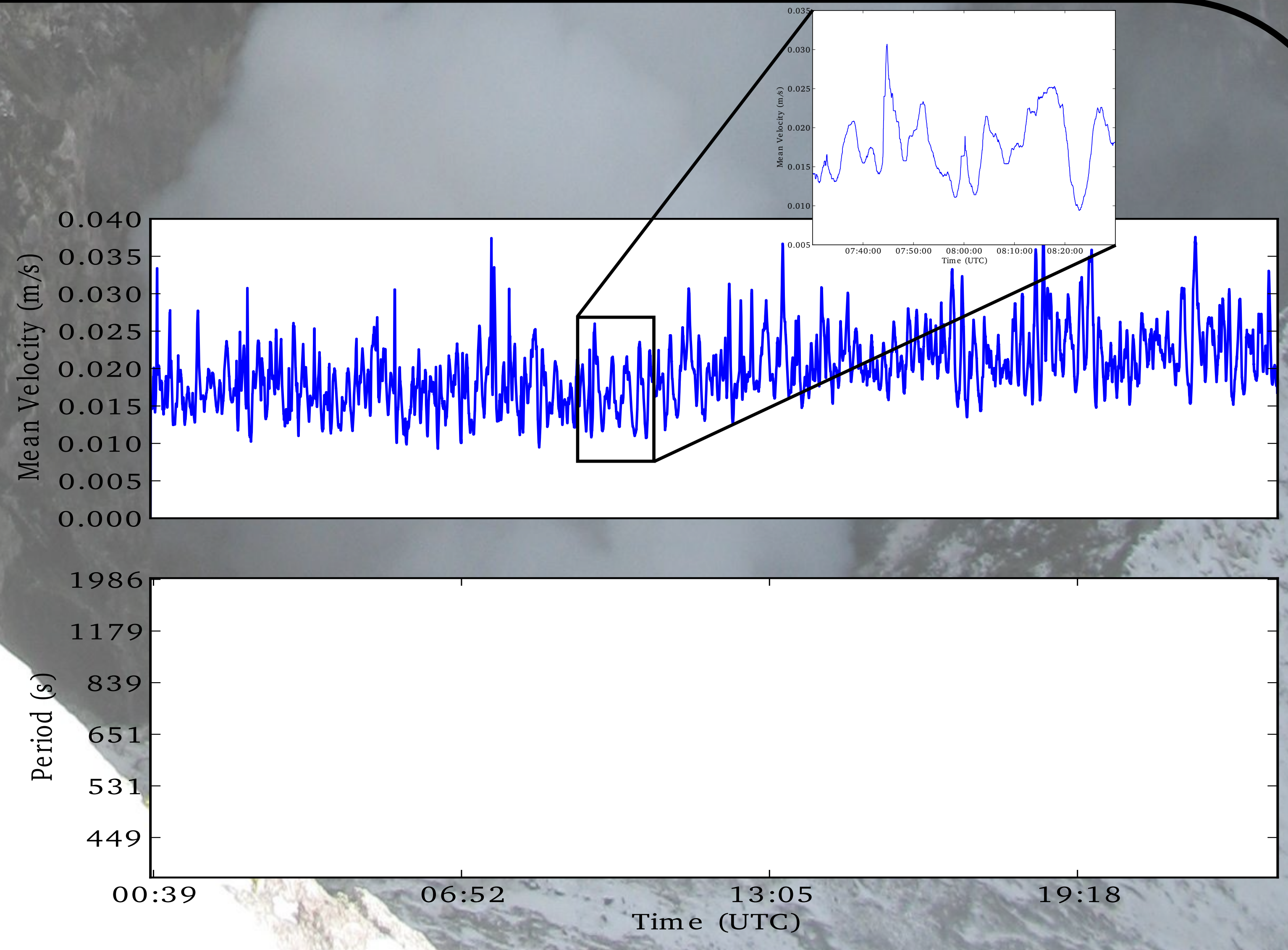
The thermal camera is mounted inside a waterproof casing at the crater rim. A rigid stainless steel and aluminium framework provides stability in the often high winds. Power is provided by an array of solar panels and wind generators situated half a kilometer further down the volcano. A Trango Systems microwave Ethernet link and a low-temperature Ethernet switch are used to connect the camera to a computer at our field camp ~2 km away. Custom written software controls the camera via the GenICam interface, typically capturing one image per second (although the camera is capable of up to 25 Hz).



Corresponding points between a LiDAR scan of the lake and the thermal images are used to reproject the images such that each pixel represents an equal area. The lake is then masked with random noise to reduce edge effects. The feature tracking algorithm is based on the two dimensional Dual-Tree Complex Wavelet Transform. This is equivalent to two separate discrete wavelet transforms using different filter banks to produce real and imaginary components. The phase shifts of the complex coefficients between consecutive frames are proportional to the motion. Motion vectors are computed using an iterative approach, with an initial motion estimate being found from coarse features. Progressively finer features are then used to add detail.



A windowed Fourier Transform periodogram shows that there may be cycles of varying length present in the ratios of gases with different solubilities, suggesting a periodic variation in the proportion of relatively shallow to deep degassing.



Averaging the motion vectors in each frame and plotting a time series identifies highly periodic behaviour in the lake's velocity. A windowed Fourier Transform analysis shows that the cycles of high and low velocity have a period of around 14 minutes.